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Scientists' views about lay perceptions of volcanic hazard and risk

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Abstract

We present data from a survey of scientists from volcano observatories and monitoring institutions around the world. The scientists were asked about the hazards from the volcanoes that they work on, their perception of the likely magnitude and impacts of eruptions, and their views about local people's awareness of the risk. They were also asked about how well different groups are trusted by local people, and about their views concerning the need to warn people about changes in the volcanic risk. We show that scientists were generally concerned about risk from the volcanoes that they worked on, and also that many scientists felt that their own view of the risk was different from that of locals. Perceived trust in scientists depended upon both social factors and volcanic risk. We discuss the implications of these results for precautionary decision-making on active volcanoes.

Background

Volcanic crises involve high levels of uncertainty and high stakes. Volcanic eruptions are unusual among natural hazards because of their wide range of hazards and attendant impacts. Major eruptions are infrequent, making them a forgotten threat. This is compounded by the potential length of volcanic crises – eruptions may last for decades, as has occurred on Montserrat (Wadge et al. 2014), and require continual scientific advice for policymakers. Thus, many nations have volcano observatories, with specific mandates to monitor volcanoes and provide scientific advice when needed. At a time when the human population has exceeded 7 billion, and perhaps as many as 1 billion live within 100 km of an active volcano (Donovan and Oppenheimer 2014), the global risk from volcanoes is high. However, the low probability of eruptions at *individual* volcanoes over short, human timescales makes communication of risk difficult prior to major volcanic emergencies. Furthermore, populations in the vicinity of active volcanoes vary in their perception of risk (e.g. Gregg et al. 2004, 2008; Dominey-Howes and Minos-Minopoulos 2004; Haynes et al. 2007, 2008; Bird et al. 2009, 2010; Paton et al. 2008, 2010). Volcanologists working at volcano observatories thus have an important role in both the assessment and the communication of risk. This

involves a judgement about how to frame scientific reports and how to communicate most effectively. In part, scientists' judgements about the risk perception of the population may affect the ways in which information is framed for policymakers and the public. This is a significant issue for disaster risk reduction for volcanic risk, since scientific advice is important in the assessment of volcanic activity, and stakes are high. This paper explores this using quantitative survey data.

Disaster risk reduction (DRR) requires an integrated approach from the social and natural sciences. Hewitt (1983) reinforced the observation of White (1945) that natural hazards become disasters primarily due to social factors rather than physical ones. This has resulted in a bifurcation in the literature, with scientists focussing on better characterising hazards and social scientists focussing on vulnerability reduction. A problem with this schism is that the *social* role of scientists and of social scientists themselves is neglected in the literature. Risk is generally conceptualised as a combination of the likelihood of an event and its consequences. In DRR, risk is generally presented as a function of both hazard and vulnerability (e.g. Wisner et al. 2004), but recent DRR research has tended to focus on the latter (e.g. Hewitt 1983, 2000, 2013; Cutter 1996; Bankoff 2001; Gaillard 2010) – and within this, physical, biological and social vulnerability (e.g. Brooks 2003). Bankoff (2001) puts forward the view that vulnerability is itself influenced by its origin as a Western concept and by the assumption that

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a solution is the provision of Western expertise. This argument has led to a body of literature that seeks to incorporate in DRR both “global” scientific knowledge and local, indigenous knowledge (such as traditional methods of coping with hazards), for example Mercer et al. (2010) and Gaillard and Mercer (2013). However, the importance of local knowledge notwithstanding, in the early stages of a *volcanic* crisis, there may be heavy dependence on scientific advice and risk assessment in order to assess the likelihood of an eruption, and the views of scientists about the way that populations might be affected by hazards are important in the advisory process. Furthermore, scientists may be asked to communicate their assessment to the policymakers and to the public (e.g. Haynes et al. 2008). The ways in which scientists perceive any differences between their own view of the risk and that of the population or the policy makers is likely to affect the communication process.

Risk perception is not a simple matter of knowledge, but is affected by the presence of other risks (such as going hungry or anxiety about employment; e.g. Gaillard 2008; Wachinger et al. 2013). The relative importance of different risks to individuals may influence the behaviour of populations more than the likelihood of the events causing risk or their potential outcomes (e.g. Slovic 2000; Pidgeon et al. 2003; Pidgeon and Fischhoff, 2011; Gaillard 2008). Furthermore, the trust of populations in different sources of information can affect volcanic risk perception (e.g. Haynes et al. 2007, 2008). Trust is critically important in risk communication, particularly when stakes are high: poorly trusted information is unlikely to be acted upon. Trust can be affected by diverse factors, including perceived financial gain or loss from the risk (e.g. Eiser et al. 2007, 2008); past experience (e.g. Frewer et al. 2003); conflicting messages (Haynes et al. 2007); perceived political motivation (Poortinga et al. 2004). In general, trust is linked to perceived competence, openness and consistency (Renn and Levine 1991; Poortinga and Pidgeon 2003).

Scientists have been identified as a well trusted group by numerous studies (e.g. Haynes et al. 2008; Eiser et al. 2008), and are increasingly expected to take part in the risk communication process. Yet the L'Aquila trial in Italy and the conviction of scientists in 2012 for *“having given out falsely reassuring information to members of the public”* suggests that involvement of scientists in risk communication can be problematic (Alexander 2014). Related to this, there is a large literature concerning the effectiveness of warnings (e.g. reviews in Mileti and Sorensen 1990; Dash and Gladwin 2007). This suggests that warning is a social process, and its impact will be defined by those issuing the warning, those receiving it, and the characteristics of the message itself (Mileti and O'Brien 1992). However, much of this literature has focussed on the ways in which

warnings have been received by populations, rather than the factors that might affect the composition of a warning message itself.

In volcanology, past crises have demonstrated the complexity of managing low-probability, high-impact risks, in light of high levels of uncertainty combined with high stakes. The 1976 non-eruption of La Soufriere de Guadeloupe is an example of this. In this case, 73,000 people were evacuated for nine months as a result of volcanic activity, but no eruption occurred. Thus, with hindsight, the evacuation was perceived by some as unnecessary. Hincks et al. (2014) have showed using belief-based probabilistic methods that the decision to evacuate was appropriate given the high levels of uncertainty, but the event was still viewed by some as a “false alarm” or failure by some volcanologists at the time (e.g. Tazieff 1977). This in turn caused concern about the erosion of trust in scientists and the potential for future public resistance to scientific caution. Anxiety about the likely reaction of the public to a warning is likely to affect the decision of when warnings should be issued. Indeed, anxiety about perceived anomalies in lay risk perception may also influence the communication process, particularly if there is a fear of accusations about false alarms.

There have been several studies of lay and expert perceptions of risk (e.g. Hansen et al. 2003; Fischhoff et al. 1982; Slovic 1999; Slovic et al. 2004; Bostrom 1997; Wynne 1996). Differences between lay and expert opinions concerning biotechnology and genetically modified crops have been demonstrated, for example (e.g. Savadori et al. 2004; Wynne 2002). The hypothesis that lay people perceive risk differently to experts due to a lack of knowledge (the “knowledge deficit” model) has been challenged by increasing awareness of the complexity of lay risk perception (e.g. Hansen et al. 2003; Wachinger et al. 2013) and by the observation that experts may also be vulnerable to a range of heuristics and biases (e.g. Bostrom 1997; Eiser 2004; Rowe and Wright 2001; Slovic 2000; Sjöberg 2000; Tversky and Kahneman 1973, 1974; Kahneman et al. 1982). Scientists may have access to additional knowledge, but their engagement with their subject on a daily basis could affect their judgement of the risk, especially if there is no clear and robust method for quantifying that risk (Tversky and Kahneman 1973). Scientific judgement concerning *lay* perception of risk may also be important in the scientific advisory process that feeds into policy; for example, Hansen et al. (2003) report that experts view public concern about food risk as excessive (see also Eiser et al. 2002). This raises questions for politicians seeking to reconcile lay and expert opinions under uncertainty (e.g. Krebs 2011). It is therefore important for those responsible for managing volcanic emergencies to understand both the risk perception within the scientific community, and also its views about

public perception of risks. In terms of disaster risk reduction, a best practice approach might involve public participatory activities in order to facilitate the integration of scientific and local knowledge (Gaillard and Mercer 2013; Wisner et al. 2012). Scientists' perceptions of the public response will be relevant and this is the topic discussed in this paper.

In this paper, we present data from a survey of 95 volcanologists from 25 countries concerning the risk from the volcanoes with which they are most familiar and local people's perceptions of that risk. Scientists were initially asked about the types of hazard that could ensue from a "major eruption" of the volcano, and the magnitude of these hazards. They were also asked about the likelihood of major eruptions and the potential for temporary and permanent evacuations of populations as a result. They were then asked about their views on false alarms and precaution. Finally, scientists were asked their opinions about how well they thought that local people understand the risks from the hazards and how well different groups were trusted. We draw some conclusions from the results to inform disaster risk reduction practice around active volcanoes.

Methods

Purpose

The purpose of the study was to assess how well volcano observatory scientists think that the population around the volcano that they work on perceive the risk from that volcano, and whether this affects the scientists' own views about precautionary decision-making. Since risk communication is a two-way process, scientists' perceptions of local people are likely to affect the ways in which they frame risk communication.

Survey design

The survey was targeted at volcanologists working at volcano-monitoring institutions. It was disseminated online, using the "Volcano Listserv" facilitated by Arizona State University and also via the World Organisation of Volcano Observatories. Scientists who had experience at volcano observatories were asked to take part and were directed to the survey. It initially asked them to specify a volcano that they work on or have worked on, and answer the questions with regard to that volcano. This was necessary for comparability because some volcano observatories are responsible for many volcanoes. Furthermore, they were asked to conceptualise a "major eruption" of the volcano and the hazards that would ensue from such an eruption, acknowledging that this scenario would differ between individuals.

The survey had three main sections – a demographic section, a section about scientists' own views and a section concerning scientists' views about local perceptions.

It was available in English, French, Italian and Spanish. The demographic section asked respondents to specify their citizenships, age, gender, how long they had been in their current profession, their role in the organisation (e.g. scientist, director, technician), their discipline and highest level of education. They were also asked how rewarding they find their profession, how close to the volcano they live, how long they had lived in their community and whether or not they were emotionally attached to that community. The scale used for these questions was a seven-point Likert scale (Likert 1932), with specified end points; for example, the scale for the final question was "definitely yes" and the other "definitely no". Other points on the scale were not labelled to allow the respondent to select their position relative to the two end points. This type of scale was used for all of the scale variables in the survey.

Part 1 of the survey asked scientists for their own views.

Hazards and likelihoods

This section asked scientists to specify the hazards they would expect from their chosen volcano in a major eruption, and then to provide the most likely length and maximum likely length of any hazardous flows (lahars, debris avalanches, pyroclastic flows (PFs) and blasts). In essence they were being asked to specify a likely scenario in the event of any eruption, and which would therefore influence their advice to decision makers and the public in the case of volcanic unrest. They were then asked the likelihood of an eruption within 3, 30 and 300 years – both on a scale and as a "1 in N" frequency – and the number of years in which they felt there would "certainly" be an eruption, and the number in which there was a 50–50 chance of an eruption. They were also asked how confident they were about these answers.

Activity, forecasting and understanding

The scientists were asked questions about how much the volcanic activity changes from week to week and year to year ("not at all" to "a great deal"); how easy it is to forecast these changes and how easy it is to understand them ("extremely easy" to "extremely difficult"). These variables were defined as "change", "forecast" and "understand" respectively. In the discussion, the "forecast" and "understand" variables are used as measures of the level of uncertainty that was perceived by scientists to pervade their work.

Impacts and plans

Scientists were asked about the likely damage to property, likely loss of life without evacuation ("extremely unlikely" to "extremely likely"), need to evacuate temporarily or permanently ("not at all necessary" to "essential"), and the

effectiveness of current warning plans and current evacuation plans (“extremely ineffective” to “extremely effective”). These were defined as the “impact” variables.

Precaution and false alarms

Scientists were asked to show their level of agreement with four statements concerning precaution and false alarms (“strongly disagree” to “strongly agree”):

1. If too many warnings are given, people stop taking them seriously.
2. It's always better to be safe than sorry.
3. If one thinks there's any risk at all, the public must be warned.
4. Warnings that turn out to be unnecessary do more harm than good.

Part II repeated the questions on likelihoods, activity, forecasting and impacts, but asked for scientists' views about the perceptions of local people. For example, “how much do local people, on average, think that the activity at [volcano name] changes from week to week?” A further question about responses was added, asking how effective local people thought that they themselves would be if they had to improvise a response to an eruption (“extremely ineffective” to “extremely effective”).

Trust

Scientists were asked to rate local people's trust in the following: scientists, national governments, local governments, family and friends, local community leaders (e.g. priests, elders), and the news media (“do not trust at all” to “trust completely”).

Surveys of any population require careful design, bearing in mind the potential for sample biases. For this survey, we focussed on volcano observatory scientists and contacted them via volcanology email list, which would limit the scope of the survey to countries where use of email is widespread. We have no respondents from some countries with many volcanoes (such as Indonesia), and large numbers from Anglophone countries. There are thus some inevitable limitations on the data. There is debate in the literature concerning the placement of demographic questions (e.g. Colton and Covert 2007; Green et al. 2000). For example, Teclaw et al. (2012) found that respondents were less likely to respond to demographic questions at the end of surveys (which is the conventional placement), and that placing them at the start of the survey does not impact response rate. Since the demographic questions were important in understanding the results and also in setting up the survey – the respondents had to choose a volcano that they worked on – we placed these questions at the start of the survey.

Statistical methods

The sets of variables for scientists' own views were averaged as follows:

- The three likelihood values, $\alpha = 0.88$
- The two changeability variables, $\alpha = 0.84$
- The two understanding variables, $\alpha = 0.86$
- The two forecasting variables, $\alpha = 0.75$
- The four impact variables, $\alpha = 0.87$
- All of the trust variables, $\alpha = 0.71$
- The first three trust variables were also divided into another variable: (scientists, local authorities and national government), $\alpha = 0.81$

In addition to these variables, predictor variables were computed from the demographic data. In the context of this study a predictor variable is a variable that can be used to try to predict other variables. For example, citizenships, job description, discipline, education, gender, language and volcano were all coded and used in statistical tests to look for relationships between these variables and the other responses to the survey. Volcanoes were coded by region, tectonic setting, recent activity (in last 5, 50, 100 years), and whether they were in developed or less developed countries. Citizenships were also coded by region. A “precaution” variable was calculated by taking unweighted means of statements 2 and 3 ($r = 0.42$, $p = 0.00$). However, the other two statements, though they both concern false alarms, were less well correlated and are taken individually below. A scale variable, “years since last eruption” was also computed; however, for six of the volcanoes, the date of the last eruption is not known. All the demographic variables were assessed for multicollinearity (cross-correlation), and where this existed, care was taken to ensure that it did not prejudice results.

An analysis of frequency data established that the majority of variables were non-parametric in distribution (failed Levene's test for homogeneity of variance, and the Shapiro-Wilk test for normality). Therefore, non-parametric tests were applied to test for the influence of particular predictor variables.

The Kruskal-Wallis analysis of variance (ANOVA) procedure (H) was used to test for significant relationships where the predictor variable was discontinuous and had more than two categories (e.g. “director”, “scientist”, “technician”). This test ranks the medians of the results for each category of the predictor, and is appropriate for non-parametric data. Significance was taken at the 5% level. Similar to this, the Mann-Whitney test (U) was used for predictor variables with two categories. Wilcoxon's signed rank test (T) for related samples was used to compare the scores between scientists' own views and those of locals. This test ranks the differences between two variables (scientists' views versus their views about locals) and assesses

the likelihood of these differences occurring by chance. Relationships between scale variables were assessed using Spearman's ρ , a non-parametric correlation coefficient, and where appropriate, multiple regression analyses were carried out using a stepwise method in which variables are either added or removed from the analysis until only variables with significant values are included in the model. For variables with a scientists' view and a perceived local view, a hierarchical regression was used, to account for variance that was the result of anchoring to the scientists' own views. For the same reason, partial correlations were applied to these variables. Partial correlations are denoted by "r" and Spearman's correlations are denoted by ρ . Means of variables are denoted "M"; standard deviations are denoted "SD".

Results

In this section, we present the results of the survey in three stages. Initially, we describe the demographic patterns within the data, which were then used as predictors for the other variables. We then describe the scientists' own perceptions of the hazards and risk from their volcano. This section discusses the variability in the volcanoes represented in the survey in terms of perceived hazard, and is therefore important in framing the subsequent sections. The next section presents results concerning scientists' own perceptions of the volcanic activity and risk. It discusses patterns within the data that seem to affect the perceived risk level. Finally, we discuss the scientists' views about local people's perception of risk, and the factors that affect this. This section also models some of the scientists' attitudes concerning warnings, trust and precaution.

Demography

Of respondents to the survey (total 95), 69% were male, 62% had doctoral degrees, 85% had worked at volcano observatories as scientists, 7% as directors; 41% had lived in their current community for more than 20 years and 56% lived within 100 km of their specified volcano. The mean age of respondents was 43, and the total age range was 23–75. In total, scientists of 27 nationalities responded. In terms of the volcanoes, 53% of respondents worked at potentially (rather than persistently or currently) active volcanoes; 95% of the volcanoes were in populated areas (within 100 km of a settlement); 25 different countries were represented and 82% of the volcanoes were subduction zone volcanoes. In total, 51% of the volcanoes had been active in the last 5 years, 64% in the last 50 years and 77% in the last 100 years. We also distinguish persistently active volcanoes as those which have been active for periods of 10 years or more at the time of the survey – 46% of the volcanoes fall into this category. A total of 67% of the volcanoes were located in

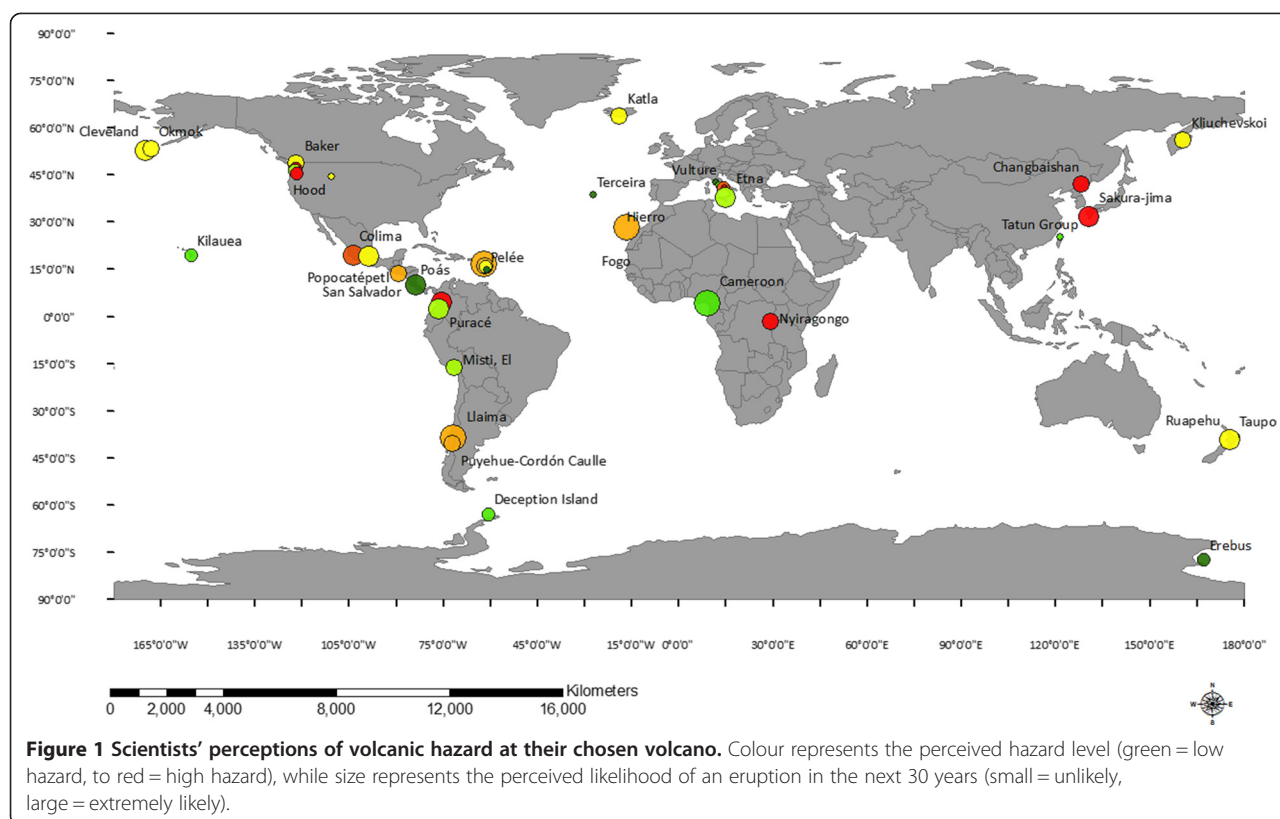
developed countries, and the rest in developing countries (as defined by the International Statistical Institute, 2013) – this is taken as a first-order measure of resourcing between nations, though we recognise that it is not a perfect measure.

Figure 1 shows the scientists' perceptions of volcanic hazard at their chosen volcanoes. The colour of the symbol represents the perceived hazard level (on a scale from "not at all hazardous" to "extremely hazardous"), and the size represents the likelihood of a major eruption within the next 30 years. Where there were multiple responses for a single volcano, average values are shown. There was considerable variation in perceptions of hazardousness for some individual volcanoes. In terms of the types of hazard, tephra fall was the most widespread, regarded as a problem by 60% of respondents. Pyroclastic Flows (PFs) were viewed as a hazard by 46% of respondents. Gas emission was the least widely reported hazard, at 15% of volcanoes. In general, maximum expected VEI for the eruption correlated well with the estimated length of flows from individual volcanoes for lahars, debris avalanches and PFs, but not for lateral blasts, perhaps suggesting that these events have an uncertain provenance (are more difficult to anticipate). Subduction zone volcanoes were consistently associated with higher magnitude hazards.

For volcanoes with multiple respondents, there was general agreement about the likely maximum lengths for lava flows and lahars, but less agreement about PFs, blasts and debris avalanches, again suggesting that there is more uncertainty concerning more extreme phenomena. Estimates of the maximum PF distance were particularly varied, with standard deviations > 10 km for most volcanoes. This suggests that volcanologists, even those working on the same volcano, may vary in how they define a "major eruption" and in their perceptions of the likely phenomena that the volcano is capable of producing. The distance that the scientist lived from the volcano correlated negatively with the amount of information available – scientists tended to live further away from volcanoes about which there is relatively little information ($\rho = -0.29$ $p < 0.01$). Some volcanologists were not comfortable with providing numerical values, either for hazard magnitude or for probability of eruption. The variety in estimates demonstrates the uncertainty inherent in volcanic activity.

Scientists' views about volcanic risk

This section reviews the scientists' own views about the volcanic hazards and risk at the volcano. In general, volcanic activity was viewed as changing at a moderate level from year to year, and as being relatively difficult to understand or forecast over any timescale. Scientists who had been in their jobs for longer tended to think that volcanic



activity changed less both week to week ($\rho = 0.22$, $p < 0.05$) and year to year ($\rho = 0.31$, $p < 0.01$), which might suggest a longer term perspective in scientists with greater experience. Scientists living closer to the volcano tended to view understanding the changes in the volcano's behaviour as easier on both timescales than those who lived further away ($\rho(\text{week to week}) = 0.28$, $p < 0.01$; $\rho(\text{year to year}) = 0.36$, $p < 0.01$), again suggesting that scientists who are willing to live closer to the volcano are generally more confident about understanding it. Volcanoes that were viewed as having lower maximum VEIs also tended to be viewed as easier to understand on a week to week basis ($\rho = 0.28$, $p < 0.05$). This may be the result of these volcanoes being persistently active and showing similar patterns of activity over medium timescales, and more information about them being available.

With regard to impact variables, the majority of scientists felt that a temporary evacuation would be necessary when an eruption happens ($M = 5.9$, $SD = 1.7$). There was considerable variation in views concerning the effectiveness of current evacuation plans ($M = 3.9$, $SD = 1.8$). There was, however, greater confidence in current warning plans, into which scientists may have more input ($M = 4.3$, $SD = 1.8$). Older respondents were more likely to think that permanent relocation would be necessary ($\rho = 0.25$, $p < 0.05$). People who described themselves as emotionally attached to their current community were

less likely to think that loss of life would be high in the event of no evacuation ($\rho = -0.23$, $p < 0.05$) and more likely to think that current warning systems and plans were effective ($\rho(\text{warnings}) = 0.24$, $p < 0.05$; $\rho(\text{evacuation}) = 0.30$, $p < 0.01$). Volcanoes about which a lot of information was available were also considered more likely to be judged to have effective warning systems ($\rho = 0.21$, $p < 0.05$). Volcanoes in developing countries were considered to have less effective warning ($U = 1130$, $p < 0.05$) and evacuation plans ($U = 1123$, $p < 0.05$). They were also more likely to be associated with a need for permanent evacuation ($U = 521.5$, $p = 0.001$).

Differences between scientists' views and their opinions of local views

In general, scientists felt that local people viewed eruptions as less likely than they themselves did (Table 1).

Table 2 shows the differences between experts' views and their views about lay perceptions concerning the volcanic activity levels and the challenges associated with forecasting. It demonstrates that scientists generally felt that local people did not have realistic perceptions of the volcanic activity.

In general, almost half of respondents felt that local people underestimated the challenge of forecasting and understanding volcanic activity. This could be viewed as a failure to appreciate the uncertainty inherent in volcano

Table 1 Scientists' views about local perceptions of risk in relation to their own, for the three periods

	Locals think eruption more probable	Locals think eruption as probable	Locals think eruption less probable	Wilcoxon T
Likelihood in 3 years	13	29	58	268 p = 0
Likelihood in 30 years	12	17	71	255 p = 0
Likelihood in 300 years	7	23	70	95.5, p = 0

Values are in % of those scientists who responded.

forecasting. However, a significant number (around 30%) thought that local people viewed these activities as more challenging – and the majority of respondents clearly felt that their own perception and that of the local people were different in some way.

The differences between scientists' views and their perceptions of local people's views for impact variables are shown in Table 3. This demonstrates that the majority of scientists again think that there are discrepancies between their own views about eruption impacts and those of local people. In particular, a significant proportion view eruption impacts as likely to be greater than local people anticipate.

Predicting the discrepancies

People at volcanoes with a high VEI were more likely to view local perception of risk within 3 years as lower than their own ($r = -0.33$, $p < 0.05$). Scientists at volcanoes with a high VEI also felt that local people viewed warning plans ($r = -0.40$, $p < 0.01$) and evacuation plans ($r = -0.31$, $p < 0.05$) as less effective than they did themselves. This suggests a perceived problem with local awareness of information about volcanic risk from hazardous volcanoes.

Hierarchical regression analyses were carried out for the individual impact variables. Results are shown in Table 4.

Table 4 shows that the planning variables could be modelled by controlling for scientists' views and then adding VEI as a predictor, suggesting that at volcanoes

with high VEIs, local people were regarded as underestimating the value of current plans.

There were significant positive correlations between the number of years since the last eruption of the volcano and the perceived local view of ease of forecasting ($r = 0.32$, $p < 0.05$) and understanding from year to year ($r = 0.35$, $p < 0.05$): locals were viewed as overestimating the ease of understanding and forecasting volcanoes that have not been recently active. The view that locals underestimate the potential necessity of permanent evacuations was also associated with volcanoes that have not erupted for many years ($r = 0.36$, $p < 0.05$). Both of these results suggest that scientists perceive a problem with cultural memory: locals are viewed as underestimating both the scientific challenge of forecasting and the magnitude of the risk at volcanoes that have not erupted recently and of which there is therefore less awareness.

Views on trust and precaution

Trust

The results are shown in Figure 2. This shows that in general scientists viewed themselves as relatively well trusted, compared to national governments, but also rated public trust in family and in the news media as strong. Trust in scientists, national and local governments was regarded as lower at volcanoes with a higher maximum VEI ($\rho(\text{scientists}) = -0.26$, $p < 0.05$; $\rho(\text{local authorities}) = -0.29$, $p < 0.05$; $\rho(\text{national government}) = -0.28$, $p < 0.05$). The view

Table 2 Percentages for different nominal categories representing comparisons between scientists' perception of volcanic activity and their view about local people's perceptions of activity

	Locals think it changes little/ is easy	Locals think same as scientists	Locals think it changes a lot/is difficult	Wilcoxon T
Changes from week to week	52	32	16	420 p = 0.001
Changes from year to year	69	16	15	475 p < 0.001
Ease of forecasting week to week	47	24	29	NS
Ease of forecasting year to year	49	22	29	634 p = 0.034
Ease of understanding week to week	37	28	35	NS
Ease of understanding year to year	41	29	30	NS

For example, 52% of scientists felt that the local people viewed the volcano as changing less from week to week than they did themselves.

Table 3 Percentages for different nominal categories representing comparisons between scientists' perception of local people's views regarding the eruption impacts variables

Impact variable	Locals view impact/effectiveness as greater	Locals same as scientists	Locals view impact/effectiveness as lower	Wilcoxon T
Likely damage	17	23	49	284 p < 0.001
Likely loss of life without evacuation	16	27	58	341 p < 0.001
Necessity of temporary evacuation	7	28	65	149 p < 0.001
Necessity of permanent evacuation	11	24	66	202 p < 0.001
Effectiveness of warning plans	17	38	45	271 p < 0.001
Effectiveness of evacuation plans	19	33	48	379 p < 0.001

For example, 17% of scientists thought that local people thought that the likely damage from an eruption would be greater than the scientists themselves thought.

that local people thought an eruption less likely in the next 3 or 30 years than scientists did was associated with the view that scientists are not well trusted ($r(3 \text{ years}) = 0.37$, $p < 0.001$; $r(30 \text{ years}) = 0.29$, $p < 0.01$). For the three year period, local authorities ($r = 0.29$, $p < 0.01$) and national governments ($r = 0.27$, $p < 0.05$) were also viewed as not well trusted. Scientists who felt emotionally attached to their communities were more likely to think that trust in scientists was high ($\rho = 0.23$, $p < 0.05$). Local community leaders were trusted more in developing countries ($U = 525$, $p < 0.01$). In general, scientists who felt that there was less discrepancy between their own view of the volcanic activity and risk, and that of local people, also tended to feel that people generally trust scientists.

We analysed relationships between the interpretation variables and impact variables and the trust variables. The scientists' own view for each variable was kept constant, and the local view correlated with the other variables. Results are shown in Table 5.

Scientists who regarded warnings and evacuation plans as effective tended to think that scientists were well trusted. The view that local people thought warning and evacuation plans were effective – and also felt they could improvise a response – was associated with higher perceived trust in scientists and national and

local governments. These groups were not considered well trusted by scientists who viewed locals as under-estimating the consequences of eruption (Table 5).

Precaution and false alarms

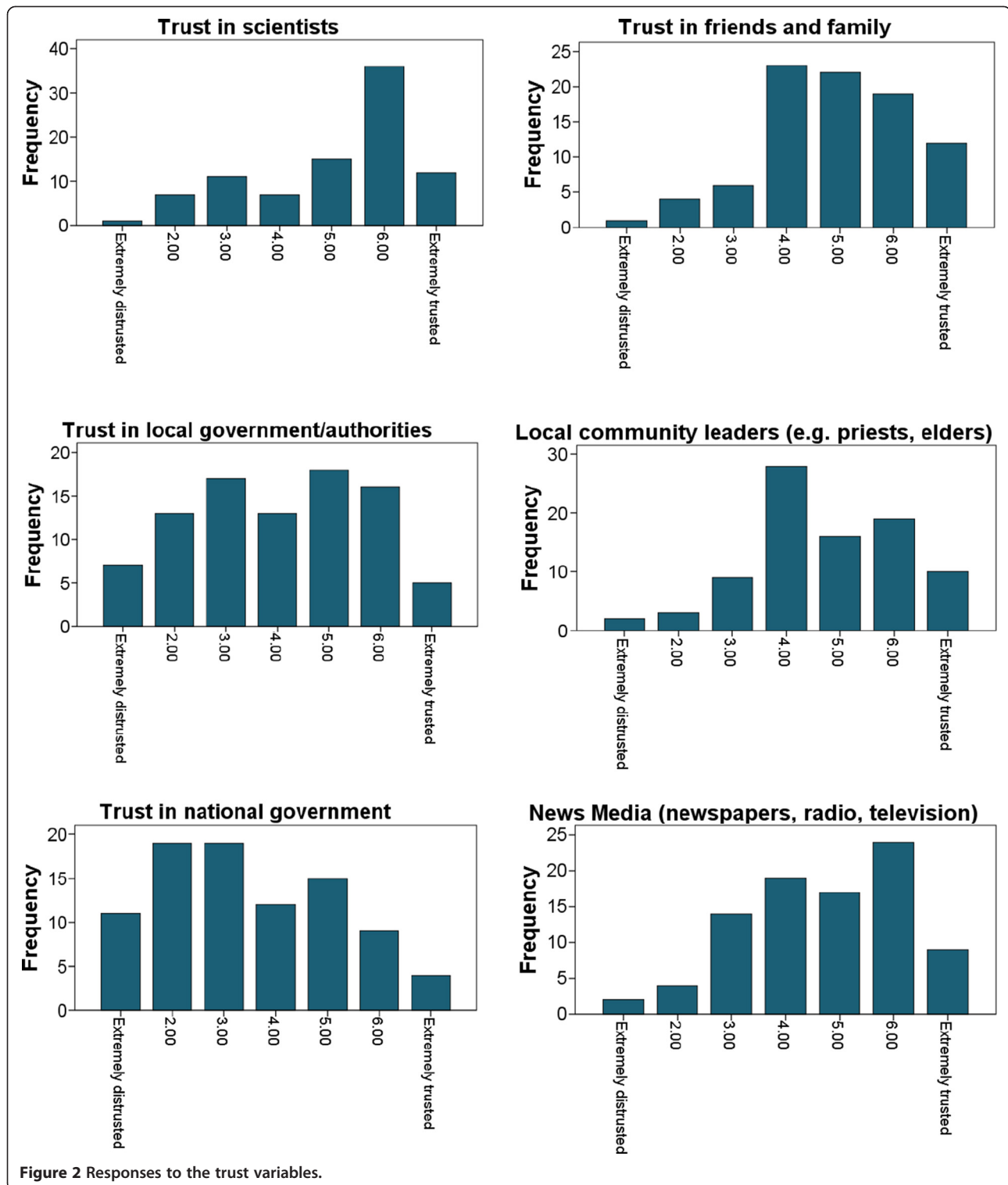
Underlying many of the concerns in this survey is the issue of precautionary decision-making: the high stakes in volcanic eruptions necessitate precaution, but the history of volcanology also implies the need for caution in avoiding false alarms. The frequency data for the statements are shown in Figure 3. Older people were more likely to agree with statement 3 ($\rho = 0.21$, $p < 0.05$) as were those who had lived in their community for a long time ($\rho = 0.32$, $p < 0.01$). People who felt attached to their current community were more likely to disagree with statement 4 ($\rho = -0.22$, $p < 0.05$). Precaution in general was viewed positively by those who had been in their profession for a long time ($\rho = 0.22$, $p < 0.05$), had lived in their current community for a long time ($\rho = 0.290$, $p < 0.01$) and were attached to their community ($\rho = 0.24$, $p < 0.05$). People from Asia and the Far East were less likely to agree with statement 3 ($H(4) = 24.6$, $p < 0.01$).

Agreement with statement 1 was less prevalent among those who felt that the volcano would produce long and damaging lahars ($\rho(\text{expected lahar distance}) = -0.37$, $p < 0.01$; $\rho(\text{maximum lahar distance}) = -0.35$, $p < 0.01$). Precaution correlated positively with estimates of a high maximum lateral blast distance ($\rho = 0.32$, $p < 0.05$), while statement 1 correlated negatively with likely blast distance ($\rho = -0.33$, $p < 0.05$) and statement 2 correlated positively with likely debris avalanche distance ($\rho = 0.33$, $p < 0.05$). In general, these results suggest that very hazardous volcanoes invite precautionary responses and less concern about false alarms.

However, scientists who regarded their volcano as highly changeable tended to support statement 3 less strongly

Table 4 Regression analyses for the impact variables and planning variables

Predictor	Share of r^2	B	t	P
Local people's view of how effective warning plans are, $r^2 = 0.37$				
Scientists' view	0.22	0.43	4.18	<0.001
VEI	0.15	-0.39	-3.72	<0.001
Local people's view of how effective evacuation plans are, $r^2 = 0.45$				
Scientists' view	0.31	0.48	4.79	<0.001
VEI	0.09	-0.31	-3.09	<0.001



than those at volcanoes that were less changeable ($p = -0.27$, $p < 0.05$). People who felt their volcano was difficult to forecast ($p = -0.26$, $p < 0.05$) and understand ($p = -0.27$, $p < 0.05$) also tended to agree less strongly with statement 2 – “it’s always better to be safe than sorry”. Difficulty in

forecasting from year to year was associated with a tendency to disagree that unnecessary warnings are harmful ($p = -0.26$, $p < 0.05$). These results suggest that high levels of scientific uncertainty led to greater ambivalence about the use of precaution.

Table 5 Partial correlations between impact and interpretation variables and trust in official sources, controlling for scientists' own views

Variable	Scientists	Local govt	National govt
Local view of changes from week to week	0.23, $p < 0.05$	NS	NS
Local view of ease of understanding year to year	-0.26, $p < 0.05$	NS	NS
Local view of need for temporary evacuations	0.28, $p < 0.01$	0.33, $p < 0.01$	0.33, $p < 0.01$
Local view of need for permanent evacuations	NS	0.25, $p < 0.05$	NS
Local view of warning plans	NS	0.29, $p < 0.01$	0.23, $p < 0.05$
Local view of evacuation plans	0.27, $p < 0.05$	0.29, $p < 0.01$	0.25, $p < 0.05$
Local view of own effectiveness if needed to improvise	0.22, $p < 0.05$	0.39, $p = 0.00$	0.41, $p < 0.001$

The final row, local view of own effectiveness, is measured by Spearman's ρ (no corresponding variable for scientists' own view).

Table 6 shows partial correlations between statement 3 and local views about volcanic activity. This suggests that while scientists' own views correlate negatively with this statement, their opinions of local views correlate positively. Thus, if scientists agree strongly with statement 3, they also think that local people view the volcano as changing a lot and being difficult to understand.

Conversely, scientists who thought that local people underestimated the changeability and uncertainty tended to agree less strongly with statement 3.

Statement 4 received higher agreement among those who thought that local people either under or overestimated the challenge of understanding the volcano from week to week ($H(2) = 10.82$, $p = 0.004$).

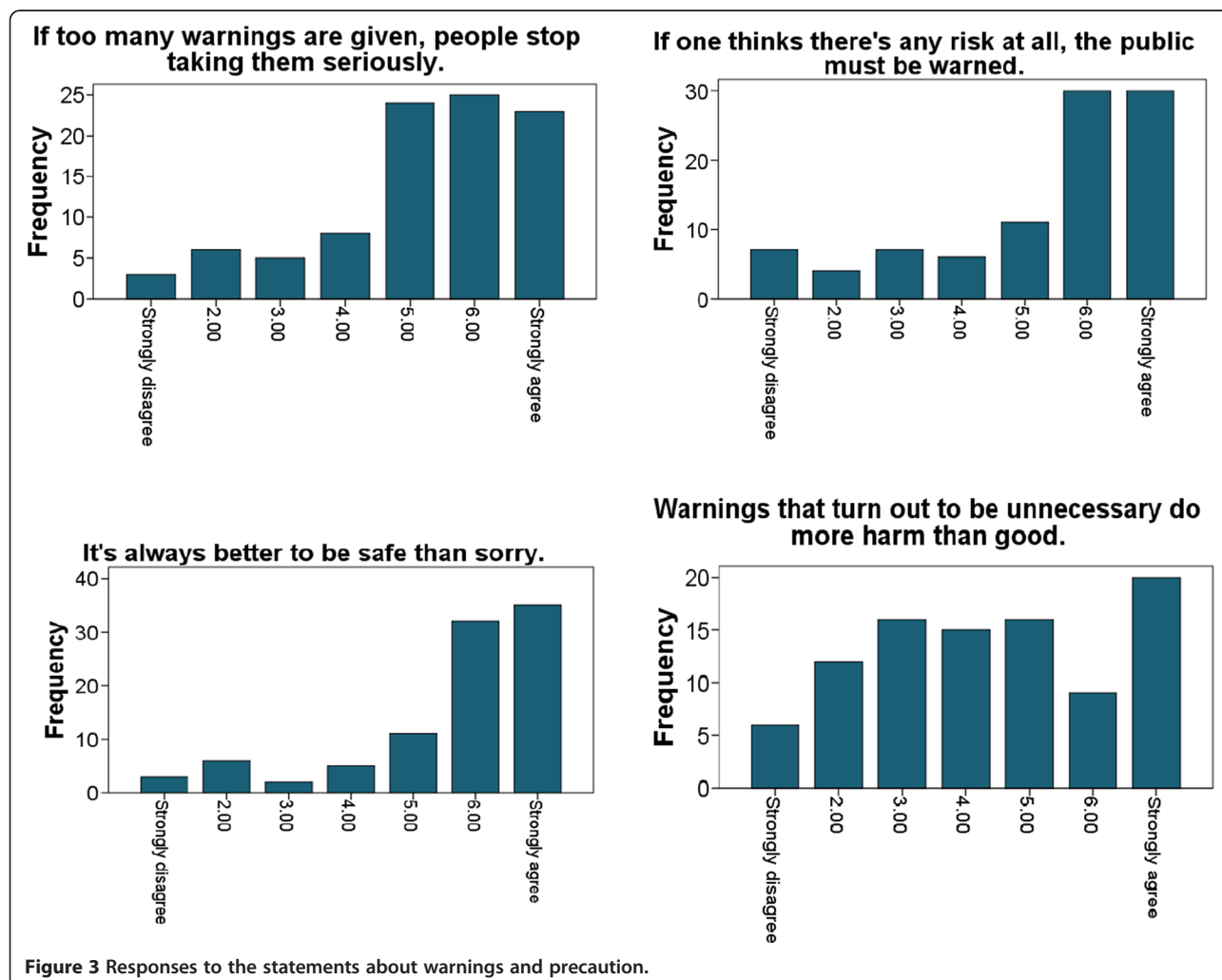


Table 6 Partial correlations for activity variables and statement 3, controlling for scientists' views

Variable	If one thinks there's any risk at all, the public must be warned
Local view of changes from week to week	0.27, $p < 0.05$
Local views on ease of understanding from week to week	0.26, $p < 0.05$
Local views of ease of understanding from year to year	0.33, $p < 0.01$

People who felt that local community leaders were well trusted also tended to agree that unnecessary warnings were harmful ($\rho = 0.23$, $p < 0.05$). People who felt that the news media were well trusted tended to disagree with this statement ($\rho = -0.23$, $p < 0.05$).

Modelling trust and precaution

Trust in scientists can be predicted by some of the discrepancy between scientists' and perceived local opinions about the necessity of temporary evacuation and the difficulty of understanding the volcano. In general, scientists who perceive greater differences between their own views about impacts and those of the public tend to think that scientists are not well trusted (Table 7). However, scientists who think that the public view the volcano as easy to understand feel well trusted, indicating a link between the knowledge that local people are perceived to have, and the trust they are perceived to place in scientists.

For the precaution variable, 26% of the variance can be explained by a combination of the change and understanding variables and the "how personally rewarding do you find your current profession" variable (Table 8). This analysis suggests that precaution is limited by a heightened awareness of the volcanic uncertainty (if the uncertainty is high, scientists tend to be ambivalent about issuing warnings), and that precaution is increased by a generally positive feeling about vocation.

A regression analysis was carried out for the two statements relating to false alarms, but no significant predictors were found.

Discussion

Scientists' perceptions of volcanic hazard and risk

In general, many of the volcanoes discussed in the survey were regarded as hazardous and as very likely to erupt within 300 years. Forecasting and understanding the changes in the volcanoes' behaviour was generally seen as challenging. Volcanoes were also viewed as having

high potential impacts on populations, with a considerable chance of loss of life in the event of no evacuation. Temporary evacuations would be necessary in almost all cases, while permanent evacuations would be likely in many. Concern about evacuation plans was more marked than concern about warning systems already in place. These results suggest that scientists are generally concerned about risk from the volcanoes, and view the likely impacts as very high. This is particularly the case at subduction zones, at long-dormant volcanoes and in developing countries – cases that were also associated (by correlation) with less effective planning. Persistently active volcanoes, typically erupting frequently over a period of 10 years or more, tended to have more information available, be considered less hazardous and perceived as easier to understand.

The perceived discrepancy between warning plans and evacuation plans could relate to control, since warning plans are the remit of scientists to some extent, while evacuation plans tend to be the responsibility of civil protection agencies. Thus scientists may be less aware of evacuation plans, or not trust local authorities to have them in place and carry them out effectively. However, it is noticeable that many of the concerns about plans for managing volcanic activity were felt more strongly at subduction zones and in developing countries. There was also greater discrepancy between scientists' views and the perceived views of local people about plans at volcanoes that are highly explosive. These results are not necessarily surprising, but do suggest that there are measureable concerns about local people's views at these volcanoes.

Scientists' views about warnings and false alarms

The responses to the statements about precaution and false alarms were complex. This suggests that scientists view these issues as contingent, and many are ambivalent about the pros and cons of issuing warnings. However, several factors emerged:

Table 7 Hierarchical regression results for the trust in scientists variable

	Share of r^2	B	t	P
Scientists' view of necessity of temporary evacuations	0.13	-0.48	-4.41	0.000
Local view of necessity of temporary evacuations	0.10	0.36	3.32	0.001
Local view of difficulty of understanding from year to year	0.06	-0.25	-2.52	0.014

The scientists' view of difficult of understanding from year to year was also included in the stepwise analysis but was not significant.

Table 8 Results from multiple regression analysis of precaution variable

Variable	Share of r^2	B	t	P
Precaution ($r^2 = 0.180$)				
Allchange	0.09	-0.30	-2.50	0.016
Allunderstand	0.08	-0.30	-2.48	0.016
Rewarding career	0.09	0.29	2.42	0.019

Other variables included in the analysis were VEI and the demographic predictors.

- Volcanoes that were considered more hazardous were associated with a tendency to issue warnings and be less concerned about false alarms;
- Volcanoes that were changeable and difficult to understand were associated with ambivalence about issuing warnings, and more concern about false alarms;
- Scientists who felt that local people had unrealistic views about the challenges of understanding the volcano tended to disagree that warnings should always be issued;
- Precaution was associated first and foremost with the uncertainty surrounding the volcanic system: high uncertainty implies a reluctance to issue warnings in all cases.

These results demonstrate the complexity of the decision to issue a warning. The potential for high impact was associated with a desire to warn, but high uncertainty tended to have the opposite effect. Furthermore, those scientists who felt that the local population had inaccurate views about the challenge of understanding the volcano tended to be more ambivalent about issuing warnings. Scientists who thought that local people's views tended towards concern about the volcano tended to be more positive about issuing warnings. The balance between issuing warnings and being concerned about "false alarms" was thus viewed as challenging and complex. There were links with perceived public perception as well as with the general uncertainty surrounding the volcanic activity.

Understanding discrepancies

In general, scientists viewed local people as underestimating the risk of eruption. They also felt that local people did not have realistic views about the changeability of the volcanic system, the difficulties associated with forecasting and understanding it, and the likely impacts of an eruption. Discrepancies between local people's perceived view and that of scientists were also associated with lower perceived trust in scientists and governments (Table 5). This could be conceptualised as a two-way trust relationship: scientists who trust the public's view of the risk also feel trusted. Studies have demonstrated the importance of trust in the acceptance of information

about risk (e.g. Haynes et al. 2008; Eiser et al. 2008), but it is likely that there is a level of reciprocity: those who give information have to trust those receiving it to respond accordingly.

There were several possible reasons for the perceived discrepancies in risk perception between the scientists and their imagined populations. A significant one was the eruptive history of the volcano. Memory of past events has been identified as an important factor in risk perception (the availability bias; Tversky and Kahneman 1973; see also Slovic et al. 1980). It is possible that scientists unconsciously rate this concept highly in their understanding of local people's risk perceptions. However, the prolonged study of volcanoes requires scientists to consider the experiences of past eruptions and to assess the potential future hazards from volcanoes, but the availability heuristic might lead them to overestimate the risk relative to local people who may often have less personal experience of volcanic activity (Tversky and Kahneman 1973). Likewise, the lack of daily focus on volcanoes among the population might result in a corresponding tendency to pay less attention to any hazard, and hence perhaps to estimate risk as lower. The relationship between perceived trust in scientists and the discrepancies of risk perception does seem to suggest that scientists who feel trusted also tend to have positive views of risk perception. Nevertheless, it is a cause for concern that scientists in this survey viewed the risk from specific volcanoes as high but that they considered local people to be relatively unaware of that risk, particularly at the most explosive volcanoes.

Implications for disaster management

In general, the survey data suggest that scientists perceive a problem in risk perception on volcanoes that have high explosivity, have not erupted for a long time, and those that are not well understood (including many in developing countries). Disaster risk reduction emphasises the role of local knowledge alongside scientific knowledge in decision-making for natural hazards (e.g. Gaillard and Mercer 2013). That scientists infer differences between their own view of the volcanic risk and that of local people is a significant result in the management of volcanic risk. It suggests the need for outreach and interaction between scientists and local people prior to and during a volcanic eruption. It may also be significant in understanding the ways in which volcanic hazard or risk assessments are framed by scientists in particular local contexts, since framing may be affected by interpretation of the likely audience (e.g. Wynne 2001).

The question of when to issue a warning is a complex one in volcanic hazard assessment, and the data in this paper suggest that there are a number of factors that might affect this decision, including the level of uncertainty. High perceived uncertainty was associated with an

ambivalence towards precaution. However, in cases where the hazard from the volcano was perceived to be high, scientists were more positive about issuing warnings. Some of the correlations suggest that concern about false alarms was greater where scientists felt that public perception of risk was less accurate. Other studies have suggested that false alarms do not necessarily have a negative impact on future responses to warnings if the reasoning behind the warning is explained to the population clearly (e.g. Mileti and Peek 2000) or if the uncertainty surrounding the hazard event is explained (e.g. Sharma and Patt 2012).

These findings obviously do not provide an answer to the question that has pervaded volcanology since Guadeloupe in 1976 – when to issue warnings in cases of high uncertainty. Furthermore, many scientists would argue that there is no such thing as a “false” alarm when uncertainty is high, and Hincks et al. (2014) found that, given the uncertainty in 1976, a Bayesian approach indicates that the evacuation was necessary even though the volcano did not erupt. What our data do suggest is that scientists’ perceptions of risk, their views about how trusted they are and how engaged they are with their local community are linked – and may also be linked with views about precaution and false alarms. Expectations about local perceptions of risk are also linked to views about these issues – scientists may be more inclined to issue warnings if they feel people are unprepared. In conditions of high uncertainty, nevertheless, there is a reluctance to issue warnings – particularly from scientists who think that the public underestimates the challenges involved in volcano forecasting. However, sustained engagement with local communities may aid the communication of warnings when volcanic activity increases.

Conclusions

This paper has presented the results from a survey of volcanologists in 2011. Our findings show that scientists perceive some discrepancies between their own perception of volcanic risk and that of local people. Within the scientific community, there is considerable variation concerning views about false alarms, while most scientists are in favour of precautionary decision-making. These views are dominantly related to the uncertainty, but also linked to perceptions about (i) whether the public fully appreciate the risk and (ii) whether the public appreciate the challenges involved in forecasting and understanding volcanic activity. It may be that a trusting public and a trusted public are linked in the minds of scientists, and this might affect the provision, or not, of warnings. It might also affect the timing and nature of warnings. An implication seems to be that risk communication might be most effective where scientists and communities are engaged with one another prior to the onset of volcanic activity.

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

All three authors were involved in survey design. AD analysed the results and wrote the paper with support from JRE and RSJS. All authors read and approved the final manuscript.

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